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Optimizing Logistics Processes in Cash Supply Chains

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EXECUTIVE SUMMARY

Introduction Cash plays a pivotal role in everyday life and can be considered the backbone of the economy. At all times, government institutions must ensure a sufficient supply of banknotes and coins to the public. Cash reaches consumers through various distribution channels, such as bank branches, automated teller machines (ATM), and retailers. The very challenging supply chain and logistics problem of having non-counterfeit cash available at the right time, in the appropriate quantity and quality, securely, and affordably is addressed in this dissertation. Recently, cash logistics has gained great attention. Cost-efficient and secure deliveries to ATMs, bank branches, and retailers have become necessary as a result of the financial crisis, the decline in cash usage, and the increase of the intensity and violence of raids on cash distribution mechanisms. This dissertation presents supply chain and logistics tools and models to increase the cost-efficiency, cash availability, and security of managing cash inventories and deliveries.

After years of growth, cash usage has stagnated in developed nations which can partially be attributed to the increasing acceptance and diversification of digital means of payment, including contactless and mobile payments. However, it is expected that the use of cash will not disappear in the short to medium term. This shift of declining cash usage in the payment industry yields a higher cost per transaction because the costs incurred to maintain ATMs and cash processing centres are partially fixed. To cope with the increasing need for cost reductions, cash availability, and secure deliveries and inventories in the Netherlands, the three largest Dutch commercial banks (viz. Rabobank, ING Bank, ABN AMRO Bank) and the Dutch Central Bank jointly initiated a business project in 2009. The logistics department of the VU University Amsterdam was asked to collaborate in this project, and my involvement in this collaborative project led to the information and data collection which served as the foundation for this dissertation.

The methods and techniques developed throughout this dissertation are primarily focused on the management of ATM inventories and cash distribution, but can also be used in other inventory systems, e.g., the replenishment of petrol stations and management of public bicycle and car systems. Planning cash deliveries and controlling cash inventories involves unique challenges primarily due to the high value density and strict security requirements. The quantity to be stocked in ATMs is a function of the desired availability, transport rates, and the interest rate. The interest rate determines the potential loss of interest income on the cash held in stock and in transit.

Scientific contribution This dissertation firstly identifies factors that impact the customer experience at ATMs. Cross-sectional surveys are conducted among ATM users and cash managers (respectively 2,231 and 181 respondents) and show that low ATM availability leads to a loss of

customers, that managers are unaware of the service quality attributes that determine customer satisfaction, and that managers measure customer experience incorrectly. A literature review and field research have led to a complete list of important factors that affect customer expectations and provide direction to properly measure ATM performance.

A procedure is developed to statistically forecast customer demand which estimates the demand during replenishment order lead-times and replenishment cycles. The resulting forecasts are intended for planning ATM replenishment orders efficiently and achieving a target fill-rate. The contribution is threefold: the aggregation of best-in-class forecasting techniques from the literature, the smoothing of the monthly and yearly demand patterns, and the efficient handling of inaccurate and incomplete source data. A numerical comparison with the performances of dozens of recently developed models for the scientific NN5 forecasting competition shows that the newly developed forecasting procedure outperforms all competing and recently published computer intelligence and statistical models.

The forecasting procedure is then integrated in an inventory control model that determines the sizes and timings of replenishment orders to achieve the desired fill-rate at a low cost. A new inventory problem is introduced through the combination of specific problem characteristics such as a high degree of uncertainty in demand and delivery lead-times. The developed solution method is new as well because it considers previously missed demand and introduces a global chance-constraint to allow the user to determine the likelihood of achieving the fill-rate. The performance of the (R, s, S) inventory model for stationary demand is numerically compared with the performance of the newly developed model, returning gaps smaller than 1.3 percent, while dealing with more complex, dynamic demands. An extension of this inventory model is developed by using the results of the aforementioned survey among ATM users. This survey demonstrated that users assign differentiated importance to ATM service quality depending on the circumstances, and on the time of ATM usage. The proposed model extension, which is presented as a real-time performance management system (PMS), has built-in flexibility to ensure that service levels can be met at varied times. Numerical experiments show that applying this real-time PMS has the potential to reduce logistics cost by 3.7 percent while maintaining the ATM service quality.

This dissertation also touches upon a decision problem that considers recirculation ATMs (RATMs). RATMs are capable of taking, recirculating, and dispensing cash. It is observed in practice that regular cash-out ATMs are being replaced by RATMs at a rapidly increasing pace due to their potential to greatly reduce the cost of logistics. The RATM's built-in recirculation functionality enables cash deposited by one customer to be withdrawn by the next, making the device self-sufficient to some extent. The imbalance between deposits and withdrawals makes RATMs either cash demanding or cash supplying. To exchange the cash shortages and surpluses among multiple ATMs, a new problem is

presented by combining inventory control, routing, pickup, and delivery. As opposed to traditional inventory-routing problems, the sequence of pickup and delivery jobs is critical in this new problem to ensure that sufficient cash remains available in the vehicle while minimizing the amount of cash picked-up from and/or delivered to the cash centre. A branch-and-cut algorithm is developed and results in the minimum cost for most of the realistically-sized instances, which is remarkable given the high level of problem complexity.

Managerial contribution Extensive discrete-event simulation experiments show that applying the developed inventory control models for regular ATMs in the Dutch cash supply chain, has the potential of reducing delivery, inventory, and interest costs equalling 32.0 to 37.7 million euro ($\alpha := 0.95$) per annum, which represents a 36 to 43 percent reduction of the total cost. The savings potential does not compromise the service quality; on the contrary, the fill-rate is increased from 98.3 to 99.4 percent. The cost reduction is achieved by decreasing the delivery frequency by on average 51 percent, thus reducing the security risk substantially as well.

Decision support tools for ATM managers are proposed to increase the manager's understanding of user expectations and his/her ability to accurately measure ATM performance. On a global scale, managers currently use the ATM unavailability duration as key performance indicator, without differentiating between the intensity, time, and location of ATM usage. Research presented in this dissertation demonstrates that this measure is inaccurate and does not provide a correct representation of the customer service experience. Instead, an estimate of the quantity of missed transactions is proposed as performance measure and a suggestion is made to differentiate between weights of missed transactions based on the characteristics of ATM usage.

The final research study of this dissertation concerns RATMs. If the replacement of regular cash-out ATMs by RATMs continues at the same pace in the future, all devices in the Netherlands will be RATMs within a few years. As a result, the studied problem of combined inventory control, routing, pickup, and delivery shall become increasingly common in the near future. A successful implementation of the developed solution yields cost savings of approximately 12 percent compared to existing solutions. Not only will the travel distance reduce substantially, the security risk will decrease as well due to a 54 percent reduction of the amount of cash in transit by balancing cash inventories among RATMs.

Valorisation and further research While doing my PhD I have shared preliminary findings of my research with numerous cash supply chain parties. The practical contribution finds its expression mainly from the fact that the Dutch commercial banks established a joint venture called Geldservice Nederland B.V. (GSN) on September 1, 2011, partly as a result of the substantial savings I identified during a business project in the year 2009. These identified savings were obtained by using the preliminary

inventory models which are further improved in this dissertation. Even today, the identified savings and developed models provide guidance to GSN in strategic decision making.

This dissertation provides researchers and professionals a foundation for further research and development within the cash logistics research field and cash industry. Major theoretical and practical challenges not yet researched should be pursued so as to foster the integration and collaboration of multiple specializations and/or cash supply chain parties. For instance, the introduction of price mechanisms to reward users for using specific (R)ATMs could eliminate the imbalance between deposits and withdrawals and/or reduce the transport frequency. Further research could also be focused on those aspects unique to cash logistics. For instance, variability could be introduced intentionally in ATM inventory control to account for strict security requirements, which is particularly interesting since logistics' solutions typically aim to reduce variability in demand and delivery (lead-)times. Consequently, new approaches have to be designed to tackle this challenge.